Westinghouse 100 kWe SOFC Demonstration Status

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Introduction

The development of a viable fuel cell driven electrical power generation system involves not only the development of cell and stack technology, but also the development of the overall system concept, the strategy for control, and the ancillary subsystems. Over the past ten years, Westinghouse has deployed with customers as experimental field units six fully integrated, automatically controlled, packaged solid oxide fuel cell power generation systems incorporating four generations of cell and stack technology and an evolving system technology. The ratings of these systems has ranged from 400 Watts to 25 kW, and the constituent stacks have contained from 24 cells to 576 cells. A summary table of field unit experience is shown in Table 1.

Objectives

These field units serve to demonstrate to customers first hand the beneficial attributes of the SOFC, to expose deficiencies through experience in order to guide continued development, and to garner real world feedback and data concerning not only cell and stack parameters, but also transportation, installation, permitting and licensing, start-up and shutdown, system alarming, fault detection, fault response, and operator interaction.

The world's first 100 kWe class Solid Oxide Fuel Cell (SOFC) power generation system is being supplied by Westinghouse and is sponsored by EDB/ELSAM, a consortium of Dutch and Danish utilities. This natural gas fueled experimental field unit will be installed near Arnhem, The Netherlands, at an auxiliary district heating plant (Hulp Warmte Centrale) at the Rivierweg in Westervoort, a site provided by NUON, one of the Dutch participants and will supply ac power to the utility grid and hot water to the district heating system serving the Duiven/Westervoort area. Performance objectives for the 100 kWe SOFC system are an electrical generation efficiency approaching 50% [net ac/LHV] and two years of operation.

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Technology Description

The 100 kWe SOFC generator module utilizes tubular Air Electrode Supported (AES) SOFCs of nominally 22 mm diameter by 1500 mm active length. These cells are fabricated using a plasma spray process for the interconnection and the Electro-chemical Vapor Deposition (EVD) process for application of the electrolyte and attachment of the fuel electrode. Cells fabricated using the same materials and processes but of smaller size, 16 mm diameter by 500 mm active length, have been tested in two 25 kWe class SOFC systems [576 cells each] in addition to numerous cell tests. These systems are sponsored by the Southern California Edison Company under an ARPA contract and by the Joint Gas Utilities, a consortium of the Tokyo Gas Company and the Osaka Gas Company. Through June 1996, these 25 kWe SOFC systems have operated for 5500 hours and 8000 hours respectively, have endured five thermal cycles to ambient temperature, and show no evidence of significant voltage degradation. In single cell tests these cells have endured over 100 thermal cycles from operation to ambient temperature without deleterious effect.

The 100 kWe SOFC generator module or stack is of seal-less design and employs 1152 tubular SOFCs oriented vertically and arranged in twelve bundle rows. Each bundle row consists of four bundles, with each bundle a rectangular cell array having three cells in parallel and eight cells in series. The bundle rows are connected in electrical series yielding a serpentine current path. The stack design for the 100 kWe unit differs from previous Westinghouse practice in that the natural gas reformers are integral with the insulation barriers between bundle rows, with heat supplied by thermal radiation directly from the SOFCs. (In the 25 kWe SOFC units, the reformers are hydraulically integrated with the cell stack, but heated by exhaust gas.) As in prior Westinghouse practice, spent anode gas is recirculated and mixed with fresh fuel (desulfurized natural gas) using an ejector with pressurized natural gas as the primary fluid. The stack operates at nominally ambient pressure. The outer canister of the 100 kWe generator module is cooled with process air to limit dissipation to the ambient and to limit canister temperature. Shown in Figure 1 is the stack design in schematic form. A plan view cross section through the stack is shown in Figure 2. Stack design is complete and both the cells and other generator components are in manufacture.

The 100 kWe SOFC power generation system is composed of five discrete skid mounted assemblies or “skids”. The generator skid supports the SOFC stack and the electrically powered process air heater used for startup. The Thermal Management Skid (TMS) supports the recuperators, the air movers (blowers), air and exhaust piping and air control valves, and the Electrical Distribution System (EDS), a shallow set of enclosures which houses all electrical distribution and electronic hardware including the control computer. The Fuel Supply System (FSS) skid supports the fuel and purge gas control valves, the desulfurizers, and the small steam generator used during startup along with a small water supply tank. These three skids are arranged in a rectilinear package measuring 8.42 m long by 2.75 m wide with a maximum height of 3.58 m as shown in Figure 3. The power conditioner and the hot water heater are also skid mounted, but supplied by EDB/ELSAM. The system is being designed to be in conformity with applicable European Economic Community Directives (codes and standards) and to qualify for the “CE” mark. Detailed final design is near completion and long lead time components are either on-hand or on order.

The startup process consists of heating the generator module to operating temperature using heated process air alone until the stack control temperature exceeds 600 ^{o}C, then supplementing the heating with self-generated ohmic heating of the cells and combustion of spent fuel. Above a stack temperature of 350 ^{o}C a reducing purge gas (97/3=N2/H2) is flowed through the anode side of the generator. Above a stack control temperature of 600 ^{o}C, the purge gas is supplemented with a mixture of natural gas and steam. This mixture composition is adjusted as a function of current and stack temperature until the stack is operating on natural gas alone at a temperature of 1000 ^{o}C and a current of 300 Amperes, corresponding approximately to 54 kW ac net. The elapsed time from dormancy at ambient temperature to automatic operation [1000 ^{o}C, 54 kW ac] is expected to take about one operator’s shift. The startup process is managed by the system controller and requires operator permission to progress through the states of PREOPERATION, HEAT, LOAD, and RUN. The 100 kWe SOFC startup process differs from past Westinghouse practice in that no inventory of hydrogen gas is required for startup fuel.

Estimated system performance is shown in Figure 4. Maximum system efficiency will occur at thermal balance, that operating condition where no ancillary energy is required to maintain the SOFC stack at operating temperature. The maximum efficiency of the 100 kWe SOFC power generation system is estimated as 49% (net ac/LHV) at 105 kW ac net output. Overall fuel effectiveness at this point will be 75%. System maximum power is estimated to be in excess of 150 kW ac with a fuel effectiveness approaching 80%. Field operation of the 100 kWe SOFC power generation system is scheduled to begin in the first half of 1997. The system is expected to operate for two years.

Accomplishments

AES cell technology has been demonstrated in both single cell and stack tests. A pair of single cells (16 mm diameter by 500 mm active length) has been tested for over 3000 hours and has endured over 100 thermal cycles to room temperature without evidence of degradation or other deleterious effect. In a 25 kWe SOFC cogeneration system sponsored by the Joint Gas Utilities a 576 cell AES-SOFC stack has operated for over 8000 hours and endured five thermal cycles without evident degradation. Further, this system to date has operated for over 4200 hours without outage.

A Pilot Manufacturing Facility initiated operation in February 1996 to produce the 22 mm diameter by 1500 mm active length AES-SOFCs to be used in the 100 kWe SOFC unit.

The design of the 100 kWe SOFC stack has been completed and the stack is under assembly.

The design of the 100 kWe SOFC system is nearing completion.

Benefits

The EDB/ELSAM 100 kWe SOFC system will achieve an electrical generation efficiency of 49%, [net ac/LHV] using natural gas fuel, an exceptionally high electrical generation efficiency for such a small capacity system. This high electrical generation efficiency coupled with the recovery of heat for district heating purposes can yield an overall fuel effectiveness approaching 80%. The unit thus marks significant progress toward reduction of CO_2, a greenhouse gas. In addition, with negligible emissions of NO_x and SO_x, the 100 kWe SOFC power system is environmentally benign.

Future Activities

The factory acceptance test for the system is presently scheduled for March 1997.

The site acceptance test is presently scheduled for June 1997.

Acknowledgments

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Figure 1. 100 kWe Stack Gas Flows

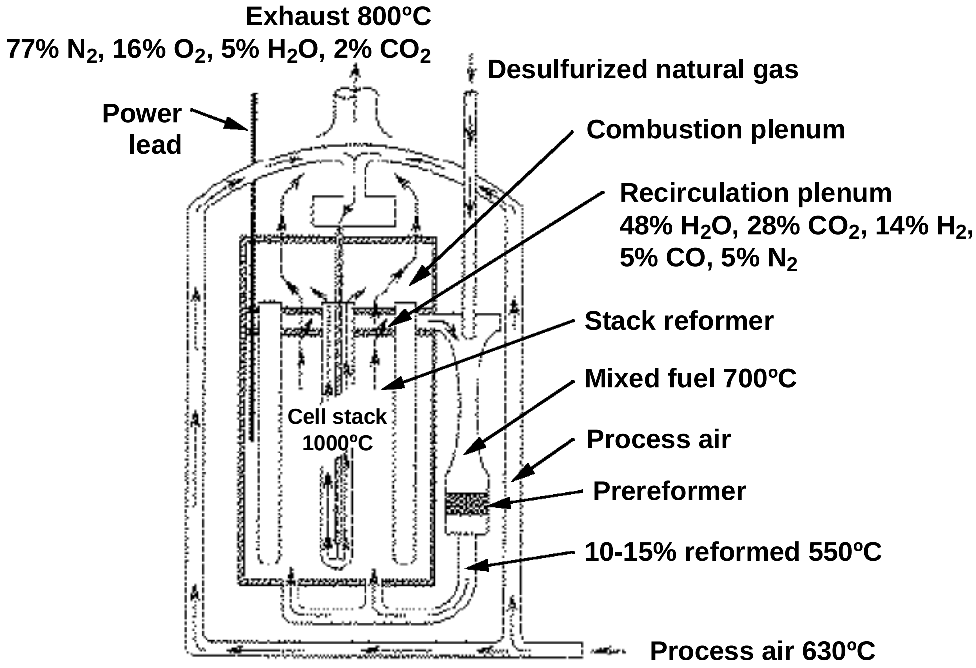

Figure 2. 100 kWe Stack Cross-Section

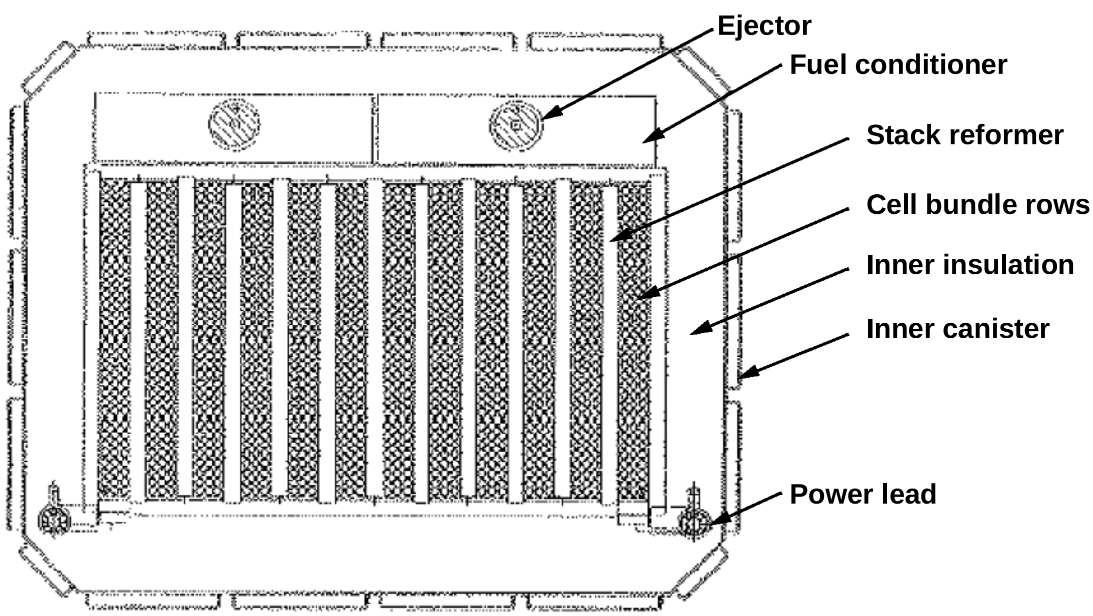

Figure 3. 100 kWe SOFC Power System Isometric View (Front)

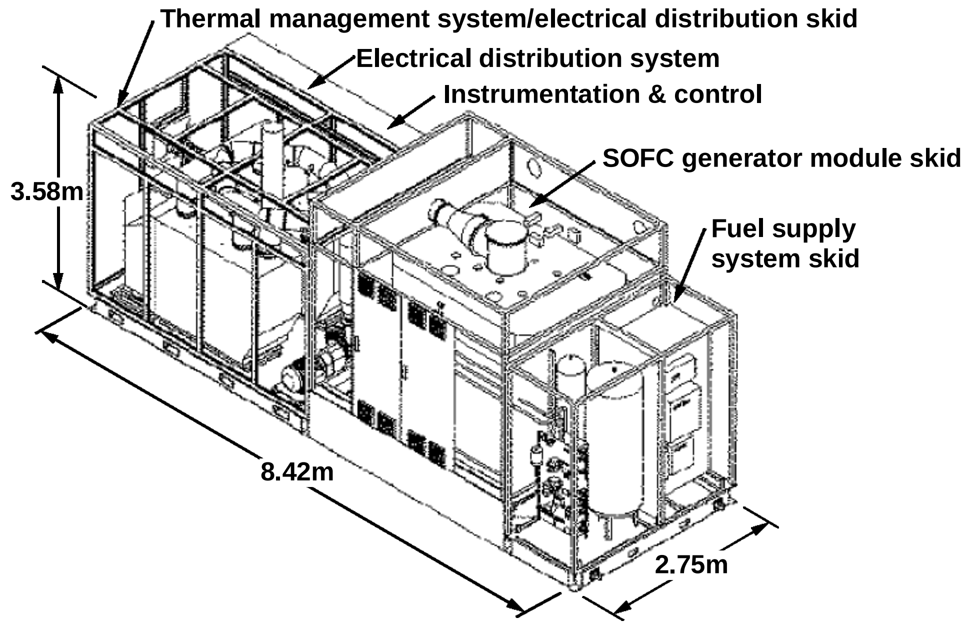

Figure 4. Calculated 100 kWe SOFC System Power Efficiencies

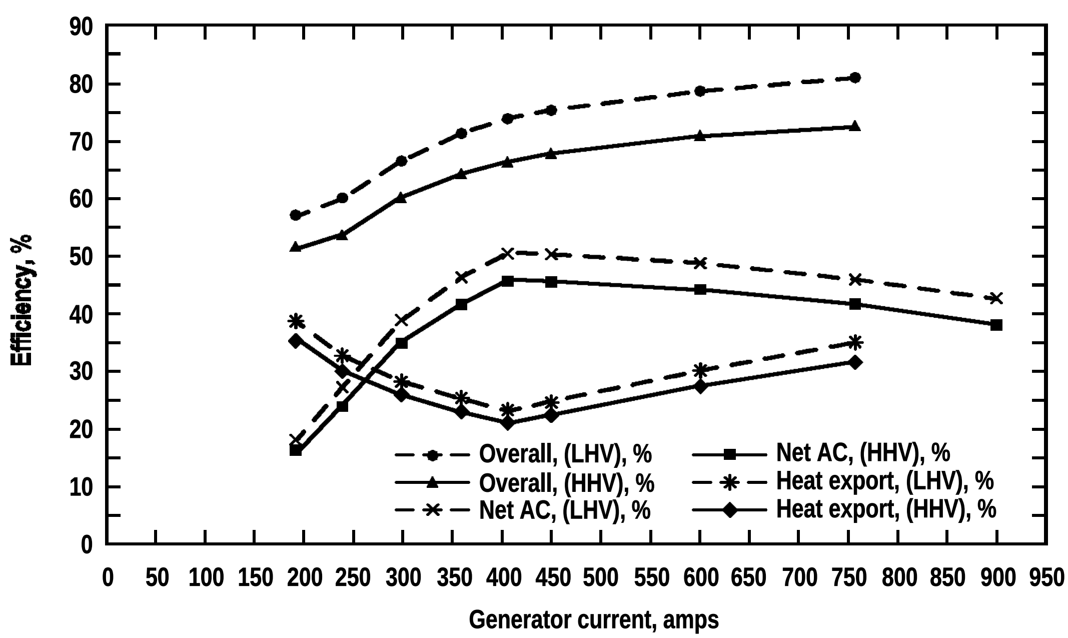

Table 1. Westinghouse SOFC Field Units

Time Year	Customer	Stack Rating (kW)	Stack Number	Cell Type	Cell Length (mm)	Cell Number	Oper. (Hrs)	Fuel	MWH
1986	TVA	0.4	1	TK-PST	300	24	1760	H_2+CO	0.5
1987	Osaka Gas	3	1	TK-PST	360	144	3012	H_2+CO	6.1
1987	Osaka Gas	3	1	TK-PST	360	144	3683	H_2+CO	7.4
1987	Tokyo Gas	3	1	TK-PST	360	144	4882	H_2+CO	9.7
1992	JGU-1	20	2	TN-PST	500	576	817	PNG	10.8
1992	UTILITIES-A	20	1	TN-PST	500	576	2601	PNG	36.0
1992	UTILITIES-B1	20	1	TN-PST	500	576	1579	PNG	25.5
1993	UTILITIES-B2	20	1	TN-PST	500	576	7064	PNG	108.0
1994	SCE-1	20	1	TN-PST	500	576	6015	PNG	99.1
1995	SCE-2	27	1	AES	500	576	5582	PNG/DF-2/JP-8	118.2
1995	JGU-2	25	1	AES	500	576	8300 +	PNG	178.8 +
Future Work									
1996	EDB/ELSAM	100	1	AES	1500	1152	TBD	PNG	

PNG = Pipeline Natural Gas

TK-PST = Thick Wall Porous Support Tube

TN-PST = Thin Wall Porous Support Tube

AES = Air Electrode Supported